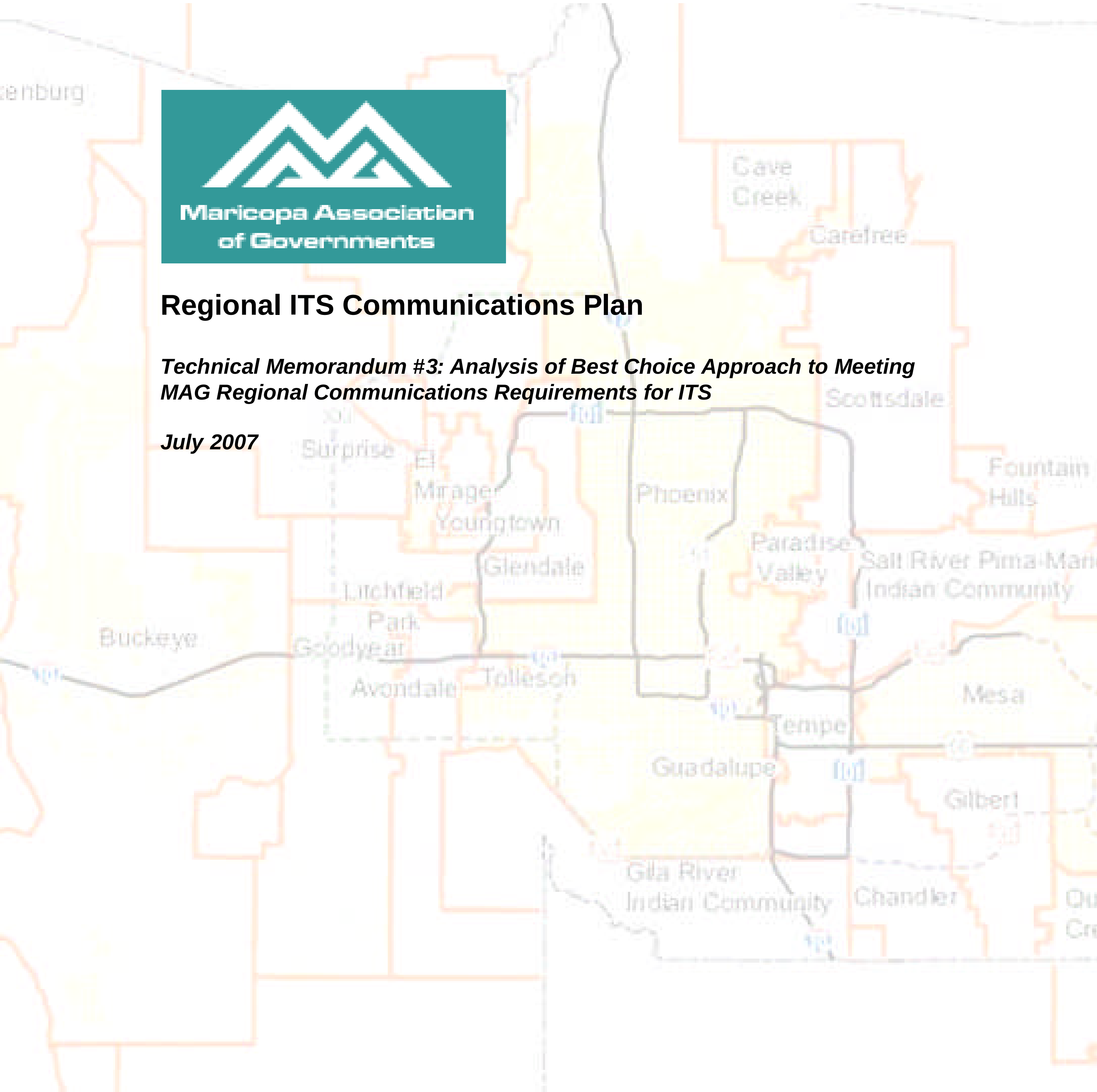
Maricopa Association of Governments

Regional ITS Communications Plan

Technical Memorandum #3: Analysis of Best Choice Approach to Meeting MAG Regional Communications Requirements for ITS

July 2007



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1.0 Regional ITS Communications Architecture Tradeoff and Recommendations

1.1 Basic Architecture Requirements

The communications architecture must support the communications load analysis developed as part of this study. The communications load analysis indicates that the regional communications network must be capable of supporting 3.5 Gbps of multimedia information sharing between adjacent jurisdictions, not including ADOT. It also indicates that sharing information between jurisdictions and ADOT related to ADOT corridors of interest to the jurisdiction will require 0.93 Gbps of bandwidth. This is based on normal daily operation and associated incidents. Thus for normal operations, 4.5 Gbps of communications bandwidth would be adequate. This data loading is based on typical data comprehension by ITS staff within the region and is not anticipated to grow significantly. The objective of *Intelligent Systems* is to reduce workload on management staff and not to increase workload. While more sensors will be deployed between the current period and 2030 and corridors will be extended or added, information exchange between jurisdictions will be primary based on incidents of common interest between jurisdictions and information required to manage contiguous corridors. Signal timing and traveler messaging coordination requires insignificant bandwidth as compared with video sharing. Similarly, IP-voice channels require low data rate. The major network data load will occur based on the following situations:

- Major Emergency within the MAG Region Requiring Evacuation
- Allowing Public Access to Real Time, Digital Streaming Video from Corridor Surveillance Cameras

In both cases, the probability is that users will demand the majority of the CCTV video available via the regional network. If this is the case, then peak data loading will approach 15 Gbps. However, peak data loading will not occur until full build-out of ITS within the jurisdictions, which per plan will be 2030. Thus, a 10 Gbps network, upgradeable to a higher data rate will meet needs within the next ten years.

The technology tradeoff analysis clearly shows that optical Ethernet is the best technology choice. Key reasons for this choice include:

- Lowest Cost for Mbps (16:1 differential compared with SONET and 25:1 compared to ATM)
- Improved Network Security (IEEE 802.1x and RADIUS)
- Comparable Quality of Service and Fiber Cut Recovery Time (50 msec)
- Unicast, Multicast and Broadcast
- True network; not point-to-point/add-drop

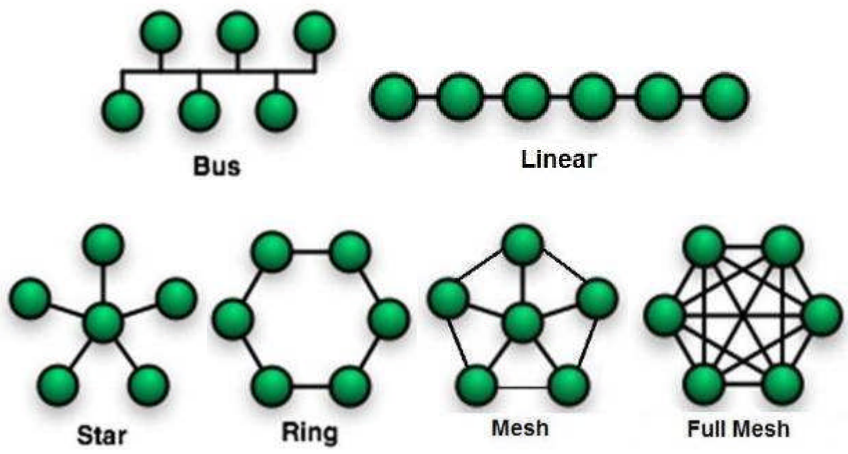
- Technology is LAN/MAN/WAN compatible
- Technology understood by most jurisdictional IS support staff
- VLAN can support functional and/or jurisdictional oriented communications
- Standard and technology not in a decline
- Simpler set up (provisioning)
- Modular and scalable

Thus the appropriate approach is to deploy Ethernet switch/routing technology.

Ethernet can be deployed in any of the commonly used communications network topologies as shown in **figure 1.1-1.** Fault tolerance is achievable only with ring, mesh and fully connected (dense mesh) topology. Mesh has an advantage over ring in a configuration where back haul paths are redundant; thus a least congested communications path can be utilized with mesh, making it appropriate to consider where a single link of the mesh is incapable of handing full bandwidth load. Mesh is also appropriate for wireless applications where one path may be temporarily blocked (either physically via large construction vehicles, new structures and/or new foliage, or through radio frequency interference) and thus functioning paths can be utilized. (Note that some of the new wireless modulation standards such as direct sequence spread spectrum, orthogonal frequency division multiplexing, and coded orthogonal frequency division multiplexing have some protection against narrow band interference and Multipath; however broad band interference can negatively impact the wireless link.) The ring topology is recommended for the regional ITS network because:

- Complies with fault tolerance standards for Ethernet Networks such as Ethernet Automatic Protection Switching (EAPS)
- Existing ADOT field communications infrastructure utilizes ring topology (i.e. Compatibility with fiber and communications nodes currently deployed).
- Many of the jurisdictional ITS networks utilizing fiber have incorporated ring architecture; inter-working optical Ethernet Rings can be supported.
- Ring topology requires less fiber and is thus less costly
- Ring topology is simpler to maintain (very defined communications paths)
- Limited bandwidth is not an issue with modular expansion capability of the Ethernet Standard. A more prudent design includes providing required communications bandwidth to meet communications load requirements.

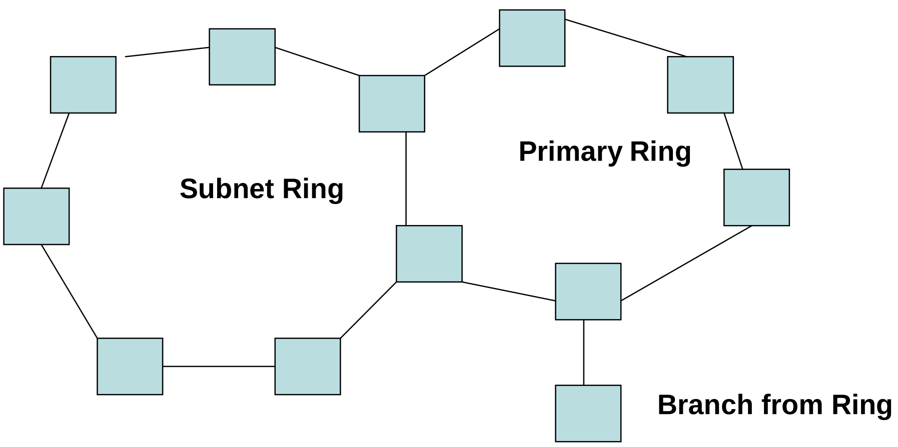
Figure 1.1-1: Network Topology Options
(Ref: Wikipedia)



There are situations where it is prudent to utilize a combination of the above topologies. Where cost may preclude extension of a ring, a branch from a ring may be appropriate. Figure 1.1-2 illustrates an example of inter-working ring topology with a branch. The branch is susceptible to a fiber cut failure in this example.

Figure 1.1-2: Example of Ring and Branch Topology

Interworking Network Rings with Branch



Topology is the geometry of the network and the deployed topology will be based on a number of factors including:

- Available infrastructure that may be utilized.
- Planned, future build-out of usable infrastructure (such as conduit and fiber) that could support regional communications network deployment
- Right of Ways available for Deployment of Communications Infrastructure
- Location and availability of locations to house communications network node electronics:
  - o Good Candidates are
    - ▪ Fire Stations (always accessible)
    - ▪ Existing Communications Node Buildings deployed to support ITS Communications
    - ▪ NEMA Environmentalized Cabinets Designed to House Roadside Communications electronics.
- Need for Connectivity in a location (or at a specific site)
- Deployment Phasing and incremental build-out.

1.2 Consideration of Existing Infrastructure

A much more extensive study will be required to identify all possible communications infrastructure that may be candidates for use in developing the regional communications network. This information was not available, except for that contained in this report. ADOT fiber current and future deployments are documented and are possible candidates for use. The least cost approach to the regional communications network would be to utilize ADOT fiber and install the small amount of electronics required for the regional network in existing ADOT field node buildings where the fiber is currently terminated. While additional analysis and test will be necessary to verify that the existing ADOT single mode fiber will support 10 Gif-E, it is believed that the dispersion may not be an issue based on distances between node buildings. **Figure 1.2-1** illustrates existing communications infrastructure as identified in a past study related to the MAG regional communications network. (The graphics includes a note indication the information was derived from 2002 dated sources). The graphics illustrates jurisdictional fiber as well as ADOT fiber, all of which has been expanded. **Figure 1.2-2** presents the ADOT fiber infrastructure as presented in the *ADOT FMS Design Guidelines-2006* document. This information will be considered in developing a topology for the ITS regional network.

Again, the topology is a concept until more in-depth analysis is conducted and appropriate inter-jurisdictional agreements are in place allowing regional use of available communications infrastructure as well as agreements on management and maintenance responsibilities of the regional network.

Figure 1.2-1: Communications Infrastructure Identified as Possibly Available to Support the MAG Regional Community Network
(Ref: MAG Regional Community Network Study)

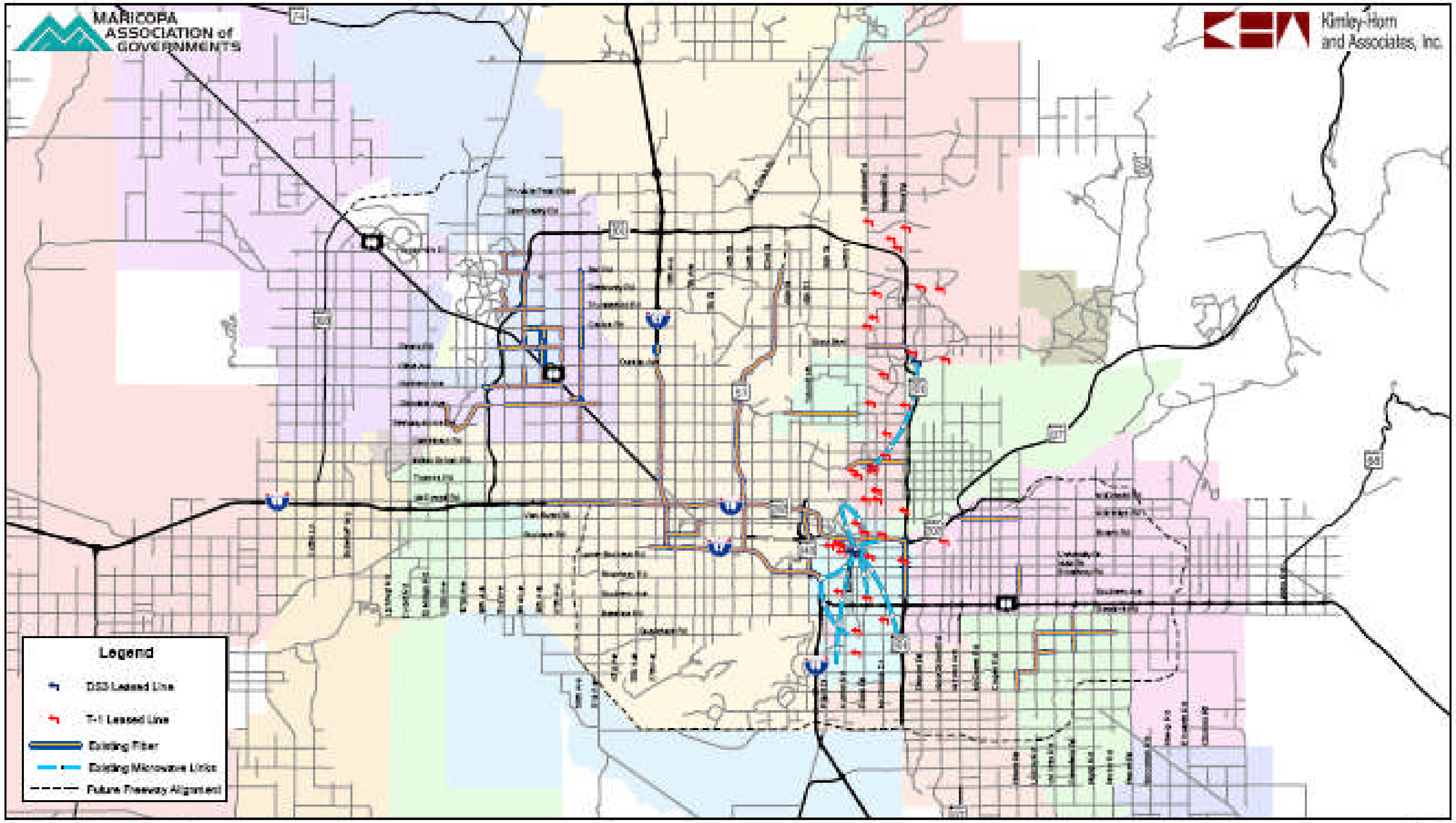
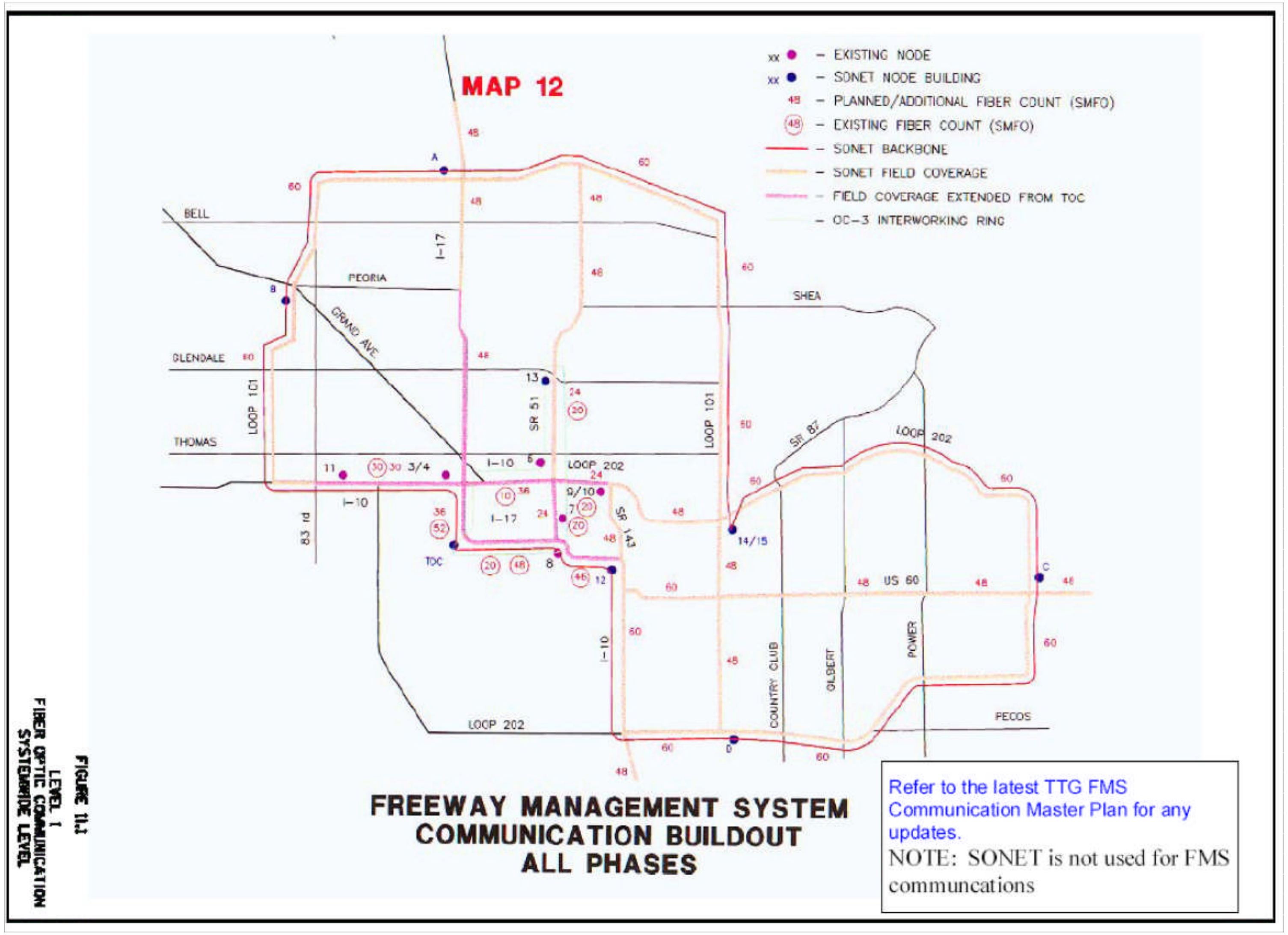


Figure 1.2-2: ADOT Communications Infrastructure
(Ref: ADOT FMS Design Guidelines, 2006)



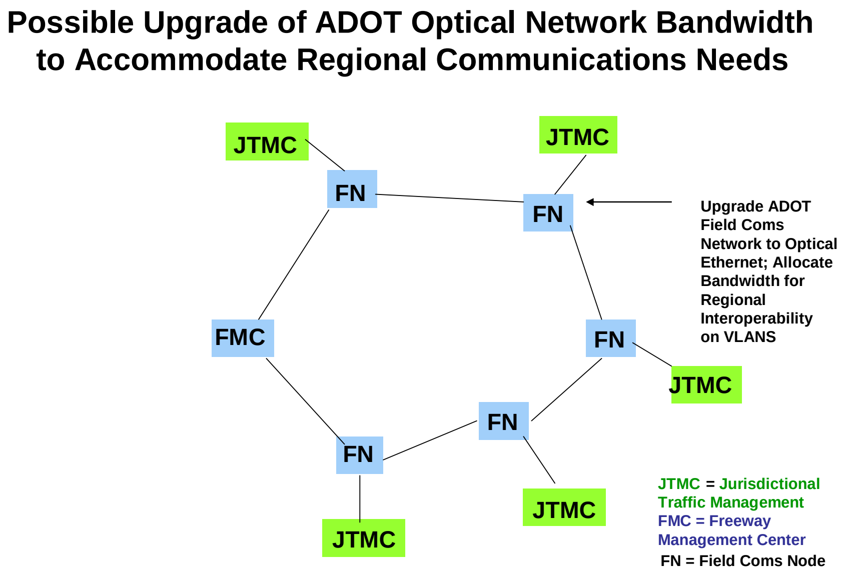
There are two possible approaches to a regional network architecture considering possible use of existing ADOT communications infrastructure:

- Expand the existing bandwidth of the ADOT Network
- Deploy an overlay, 10Gig-E network utilizing ADOT fiber and conduit.

Figures 1.2-3 and **1.2-4** illustrate these two approaches utilizing a simplistic architecture (i.e. the multiple ADOT optical communications rings are not shown nor are the node buildings on a given ring the correct number. These figures just identify the basic approach). ADOT would obviously have to approve the use of their ITS communications infrastructure for regional ITS applications. **Table 1.2-1** compares to pros and cons of the two approaches.

There is obviously the option of deploying new communications infrastructure; however, this option would be considerably more costly because new fiber and conduit would be required. Fiber and conduit represents approximately 80% of the cost of deploying communications infrastructure based on cost of Ethernet electronics. In addition, it would require much more extensive design, possible construction disruptions of traffic and business activities, as well as considerably more time to deploy.

Figure 1.2-3: Option of Expanding ADOT Field Network Communications Bandwidth to Accommodate Regional Needs



1.2-4: Option of Deploying an Overlay Communications Network Utilizing ADOT Conduit and Fiber

Possible Overlay Regional ITS Communications Network on ADOT Field Network

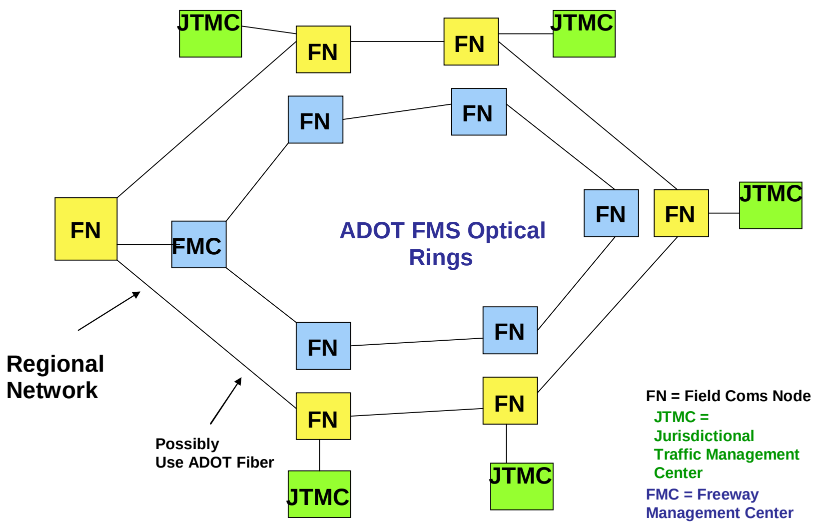


Table 1.2-1: Comparison of an Overlay Regional Communications Network versus a Combined Use Network Considering Availability of ADOT Communications Infrastructure

Pros and Cons of Approaches to ADOT Coms Infrastructure Use for Regional ITS Communications

Pros of Overlay Network	Cons of Overlay Network	Pros of Expanded ADOT Coms Bandwidth	Cons of Expanded ADOT Coms Bandwidth
No Cut Over; Minimal Impact on ADOT	Adds Additional Equipment to Nodes	Less Equipment in Node Buildings	Requires Transition/Cut-Over from Old to New
Allows Region and ADOT to Independently Expand	ADOT would Maintain (Controlled Access to ADOT fiber and Node Building)	Simpler to Maintain	Requires Common Network Management and Allocation of VLANS
Saves Significant Deployment Cost		Less Costly, if ADOT is Going to Upgrade Anyway	Requires Closely Managed Allocation of Bandwidth
No Issue with Meeting Bandwidth Needs			10Gig-E Marginal to Meet ADOT and Regional ITS Needs
Easier to Manage Bandwidth			

The recommended approach is to utilize the overlay network approach because it should have minimal impact on ADOT communications to deploy and bandwidth management becomes simpler. Furthermore, deployment of 10GigE does not impact ADOT's decision relative to upgrading their SONET infrastructure to optical Ethernet, nor any associated schedule. To accomplish deploying the overlay network will require two single mode fibers (not considering any fiber that might be applicable to interconnecting with the jurisdictional networks). Should only one fiber be available, wide wave division multiplexing (WWDM) utilizing 1310 and 1550 nm can be deployed. A device will be required at each fiber attachment point at a communications node. These devices cost less than $500 each ($1000 per backbone node). There is a small attenuation penalty utilizing the WWDM; however, it is not significant to affect the ability to communicate optically between communications nodes. The WWDM solution should only be utilized if two fibers are not available.

Figure 1.2-5 illustrates the location of ADOT fiber relative to jurisdictional TMCs. Where TMCs are not deployed, the current City Halls are utilized as a reference point. Jurisdictions may have fiber running close to the regional network ring. **Figure 1.2-6** illustrates the location of jurisdictional TMCs relative to ADOT network communications nodes. Note that most of the existing TMCs are reasonably close to ADOT communications nodes. The towns not reasonably near ADOT fiber or communications nodes are not near term candidates to deploy TMCs and some, such as Carefree, Cave Creek, Gila Bend, Gila River, Guadalupe, Salt River, are not projected to reach population levels supporting TMC deployments. Apache Junction, Buckeye, Queen Creek, and Fountain Hills are exceptions.

For interconnecting a jurisdictional ITS communications network to the regional network will require fiber access and a firewall router interconnected to the jurisdictional Ethernet Switch at the closest node. For planning purposes, the closest node is assumed to be the TMC Ethernet Switch. Jurisdictional data load analysis indicates that mot jurisdictions will not exceed bandwidth of a Gig-E interconnection with the regional network with the exception of the larger cities such as the City of Phoenix, and Mesa. Thus, use of dual, Gig-E optical interconnections will provide adequate bandwidth as well as redundancy for all but Phoenix. Note load analysis with 1.6X factor for unknown growth places Mesa marginally over the 2 Gbps bandwidth requirements in 2030 but it is adequate through 2025). **Figures 1.2-7** and **1.2-8 illustrate** several methods for a jurisdiction to interface with the regional network. The approach shown in **figure 1.2-7** does not require additional fiber. Two additional fibers (or one if WWDM is utilized) are required in the approach illustrated in **figure 1.2-8;** however interconnects to two nodes is possible providing additional fault tolerance. Figure 4.2-9 illustrates how City/Town networks become sub-networks to the MAG regional network. Firewall routers are utilized to prevent access to non-shared jurisdictional information that may be on the sub-network.

Dual firewall routers may be utilized to support redundant Gig-E interfaces between the jurisdictional network and the MAG regional network.

Figure 1.2.9 illustrates san architecture suggested in past regional network studies. While this is a workable architecture, there are issues with this architecture including:

Figure 1.2-5: ADOT Fiber Relative to Jurisdictional TMCs (or Potential Locations of TMCs if not currently Deployed Shown in Blue)

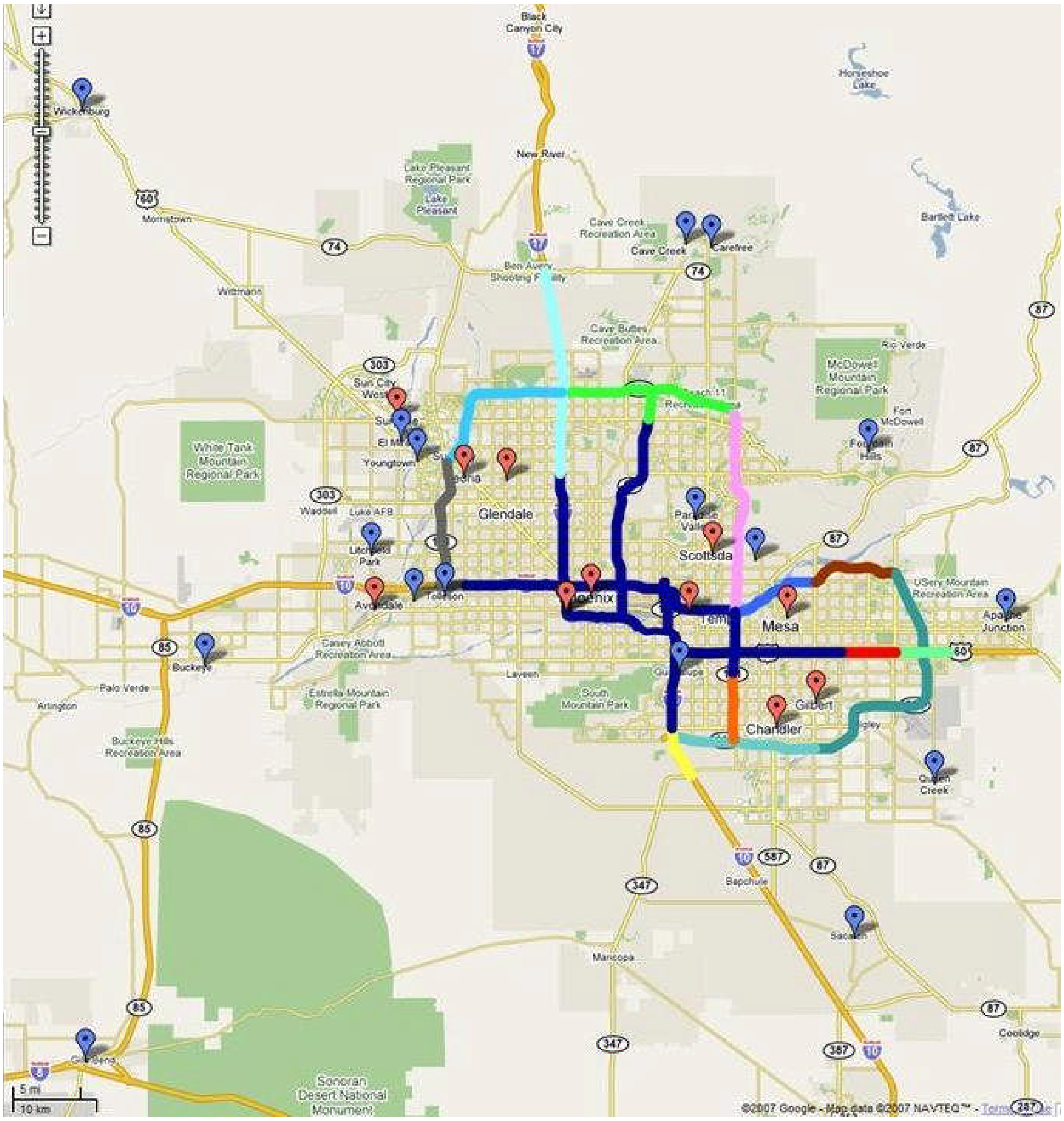


Figure 1.2-6: ADOT Communications Nodes Relative to Jurisdictional TMCs

(Notes: Yellow = Coms Node; Yellow with Dot= LRT; Red= Established TMCs; Dark Blue = Future TMCs; Light Blue= BRT; Dark Green=EOC)

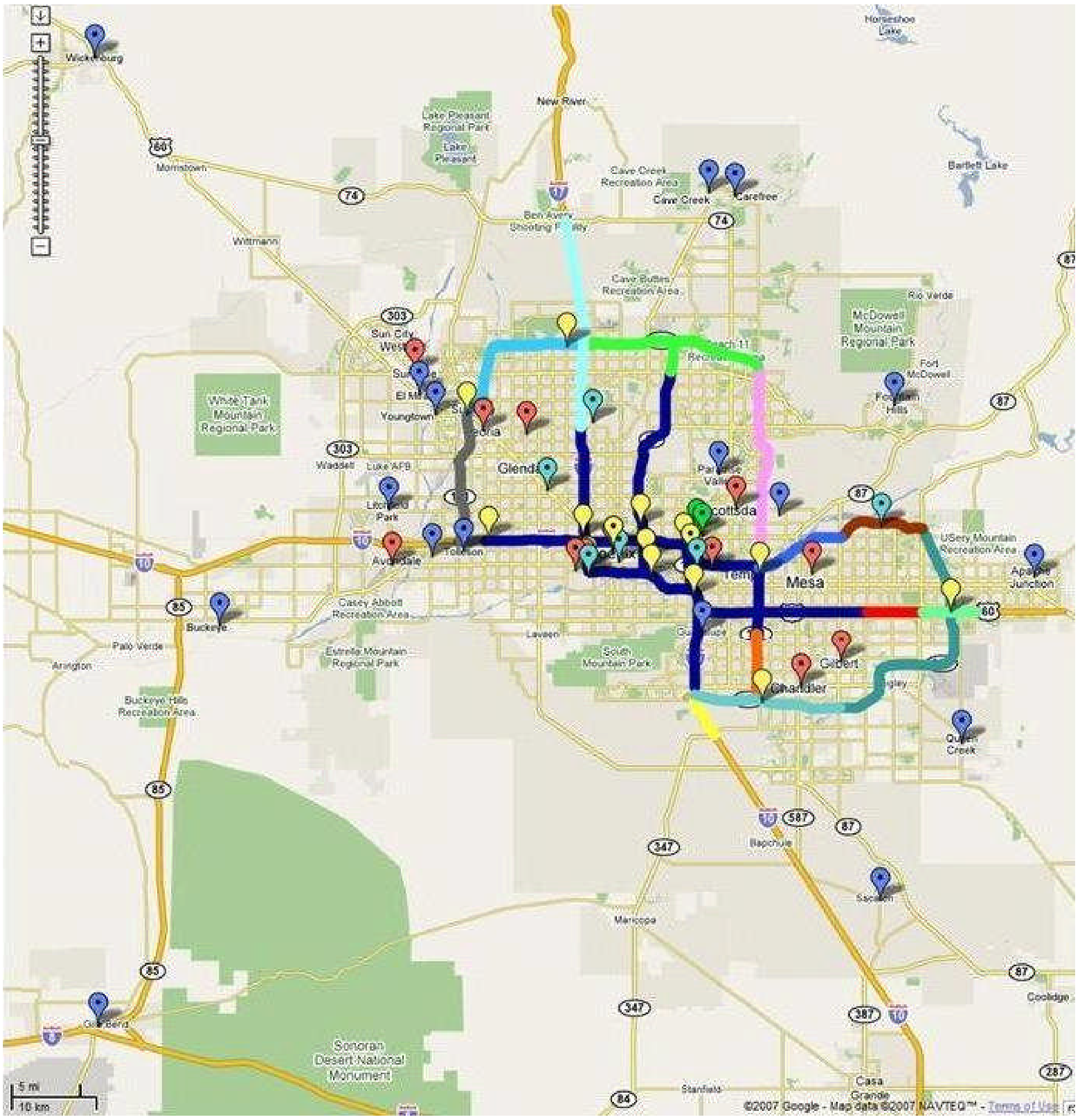


Figure 1.2-7: Deploy a Field 10Gig-E Node on the MAG Regional Network at the Closest Fiber Access Point

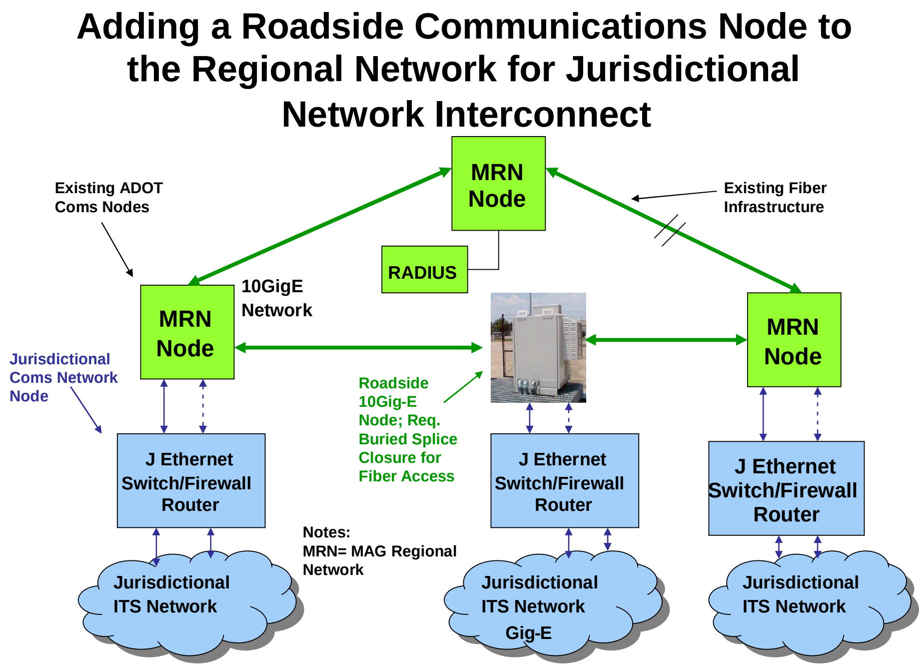


Figure 1.2-8: Using Additional ADOT Fiber to Access an Existing Communications Node Building

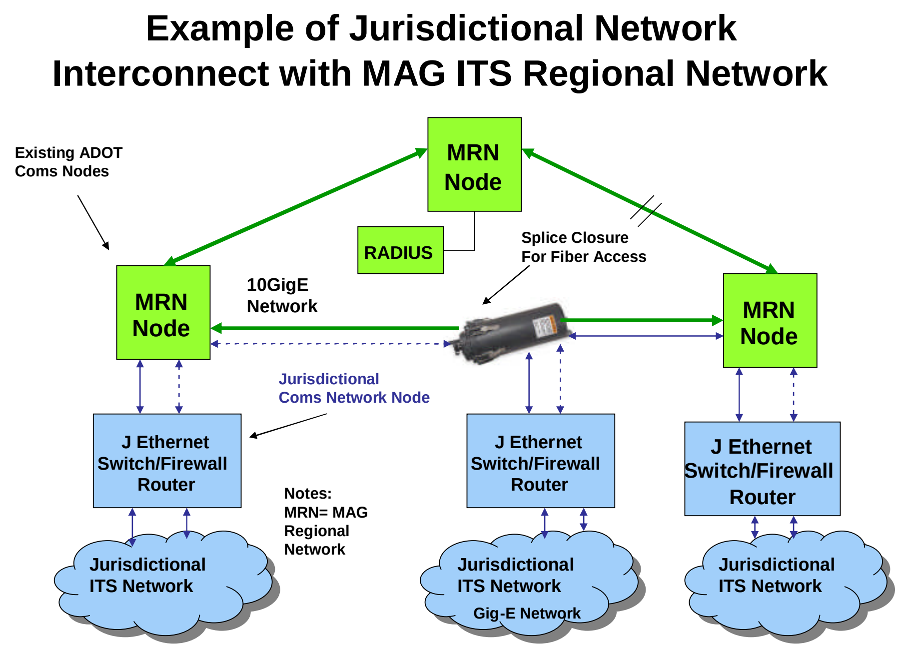


Figure 1.2-9: Jurisdictional Networks Become Sub-Networks Interoperating with the MAG Regional Network (Note Dual Gig-E interfaces May be utilized)

Jurisdictional Networks are Subnets from the MAG Regional Network

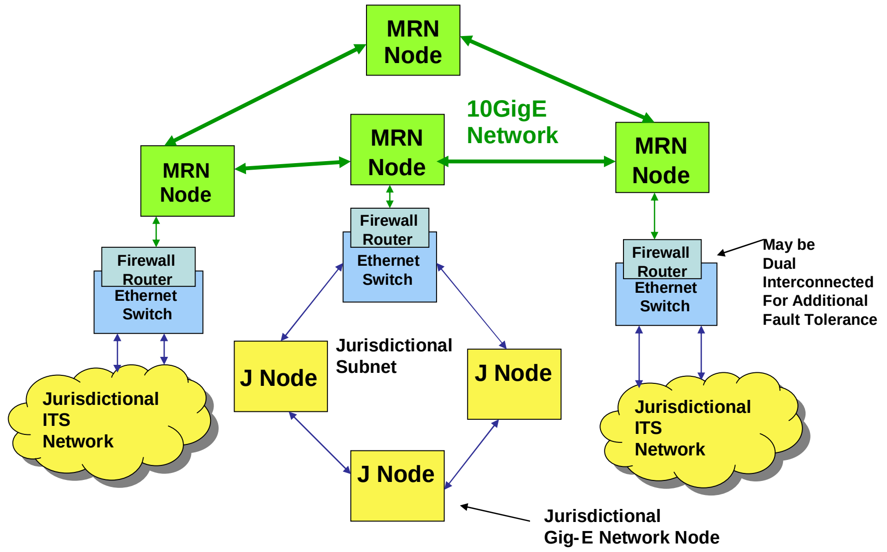
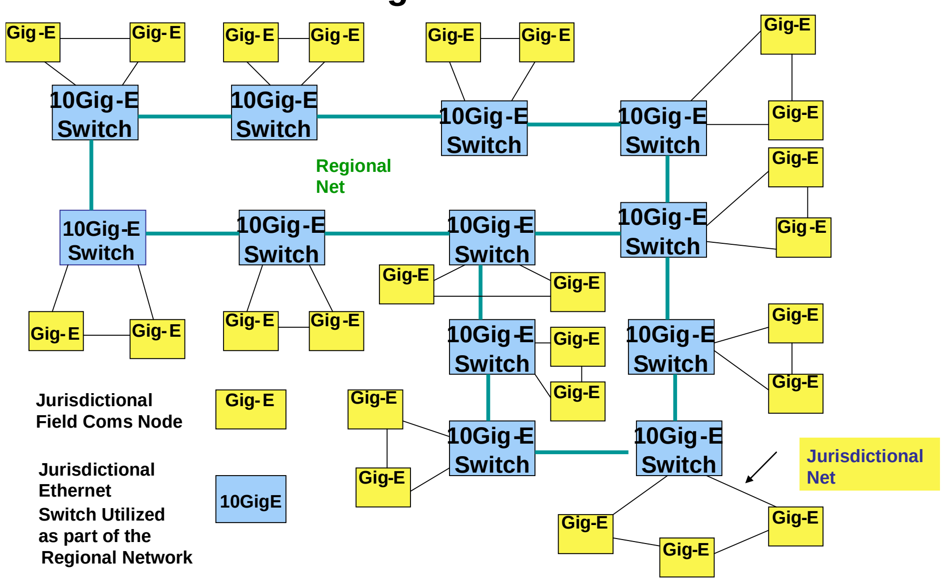


Figure 1.2-9: Architecture Suggested by Past Study

Using Jurisdictional Communications Nodes as MAG Regional Network Hubs

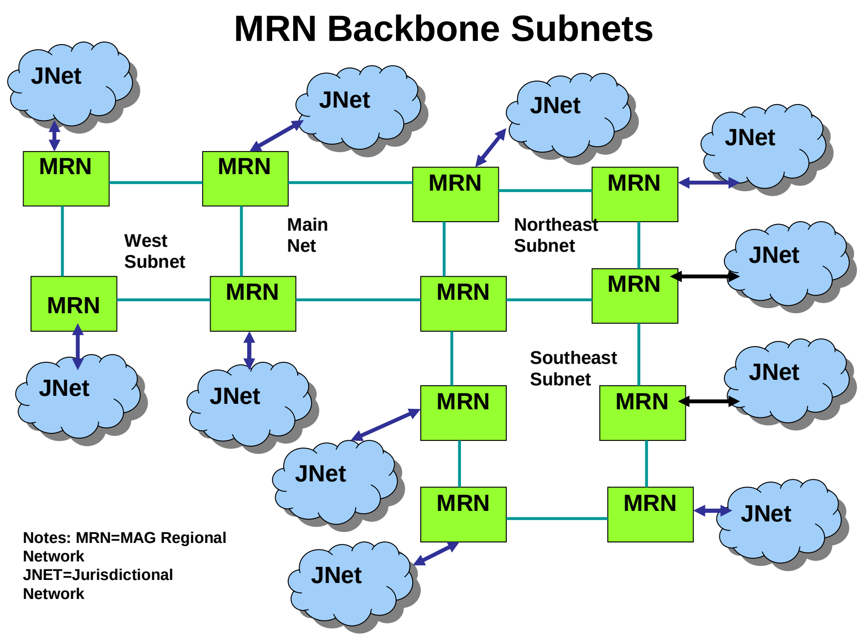


- Combines all jurisdictional communications with regional communications
    - o Backbone switching fabric must accommodate both jurisdictional as well as regional data loading
    - o Much more difficult to manage data loading
    - o Much more difficult to maintain at the regional level
- Reduces Privacy and Security of Jurisdictional Information
- Makes Future Jurisdictional Expansion of their subnet more difficult and requires coordination and approval of the regional network manager
- No clear demarcation point between regional and jurisdictions network

Even though this architecture is less costly, for the reasons listed above, it is not recommended.

Figure 1.2-10 represents multiple ring network configuration recommended by previous studies. Jurisdictional allocations to rings included:

Figure 1.2-10: Multiple Rings for MAG Regional Network



West Ring (West of I-17) Interconnects:

- ADOT FMC (Inter-work with Southwest Ring)
- Phoenix (Inter-work with Northeast Ring)
- Glendale
- Surprise
- El Mirage (Branch to Wickenburg)
- Youngtown
- Peoria
- Litchfield Park

- Buckeye
- Goodyear (branch to Gila Bend)
- Tolleson
- Avondale
- Maricopa County

Northeast Ring Node Interconnects:

- Deer Valley and Airport
- Carefree
- Paradise Valley
- Scottsdale
- Salt River with branch to Fountain Hills
- Mesa with Branch to Apache Junction
- Tempe
- MAG (Inter-work with Southeast Ring)

Southeast Ring Node Interconnects:

- Gilbert
- Chandler (branch to Gila River)
- Queen Creek
- Guadalupe

Pros and Cons of the 3 Ring Network Topology are summarized in **table 4.2-1**.

Table 1.2-1: 3 Ring Topology Considerations

Pros and Cons of 3 Ring Topology

Pros of 3 Ring Topology	Cons of 3 Ring Topology
Supports Phased Buildout	More Difficult to Support Multicast using Protocol Independent Multicasting (PIM)
Reasonably Follows Geographic Deployments of TMcs	Much More Network Loading using Dense Pruning per PIM
Reasonably Follows ADOT Fiber Path	More Difficult to Recover Multicast Communications Upon Failure Recovery
Possible Data Load Reduction on SE Ring	More Difficult Architecture Using Jurisdictional Ethernet Switches as Regional Communications Node (Especially Linear Branches)
Less Susceptible to Ring Segmentation	More Complex to Maintain
Can be Configured for Network Management by MAG, ADOT or MACDOT (Note Single Ring Provides Similar Options)	Rings not Load Balanced

Basically, build-out phasing and fiber/conduit availability will be the major considerations determining the number of rings deployed. This should be determined upon conduct of a more in-depth study which identifies available infrastructure that the owing jurisdiction is willing to share to support regional interoperability.

1.3 Topology of MAG Regional ITS Network Recommended as a Basis for this Plan

Figures 1.3-1 and **1.3-2** illustrate MAG maps related to jurisdictional areas and locations as well as ADOT freeway infrastructure and build-out plans. These maps are utilized as the basis for MAG Regional Communications Network topology planning.

First, it is prudent to have jurisdictions with contiguous boundaries and corridors on a common subnet. The reason is that it keeps area communications related to ITS coordination of contiguous corridors and incidents requiring mutual assistance off the primary backbone, if not of interest to other jurisdictions. In a major emergency involving many areas of the region as well as collection of 511-source information, subnet architecture does not reduce communications loading on the main backbone ring. Furthermore, there is common information of interest by jurisdictions including regional weather, terrorist alert status from the EOC/DHS, jurisdictional coordination with ADOT, and other general ITS information that will flow to jurisdictions. Furthermore, when a regional ITS data achieving center is established, information will periodically be transferred from jurisdictions to the data achieving center and information may be requested from the data achieving center by jurisdictional planners.

Table 1.3-1 provides a logical grouping of jurisdictions based on common interested boundaries and corridors. **Table 1.3-1** also identifies the projected population for the jurisdictions in 2030. Jurisdictions color coded in green (20K or less population) will most likely not have a formal TMC and may be utilizing County Sherriff emergency management (PSAP and possibly police services) or contracted emergency resources for fire and emergency medical. Similarly, jurisdictions with a population from 20K to 50K will most likely have a small TMC with a few workstations and possibly a wall plasma display to present CCTV Video. Above a population of 50K, most likely jurisdictions will have a more formalized TMC. Table 1.3-1 does not include Maricopa County (MCDOT) that is responsible for county roads and areas of the county not incorporated (or where the jurisdiction does not have the resources to manage and maintain traffic signals). MCDOT essentially encompasses the areas shown in **figure 1.3-2** not color-coded to represent jurisdictional boundaries for cities and towns. County population in 2030 is projected to be around 250,000 (round up from MAG projections). Again, the assumption is made that jurisdictions have their own ITS Network and provided integrate all jurisdictional information related to ITS; the regional network is not intended to link all jurisdictional centers. Major centers, such as the County EOC would be an exception.

Figure 1.3-1: ADOT Freeway Infrastructure and Planned Build-out
(Ref: MAG Regional Transportation Plan – 2007 Update)

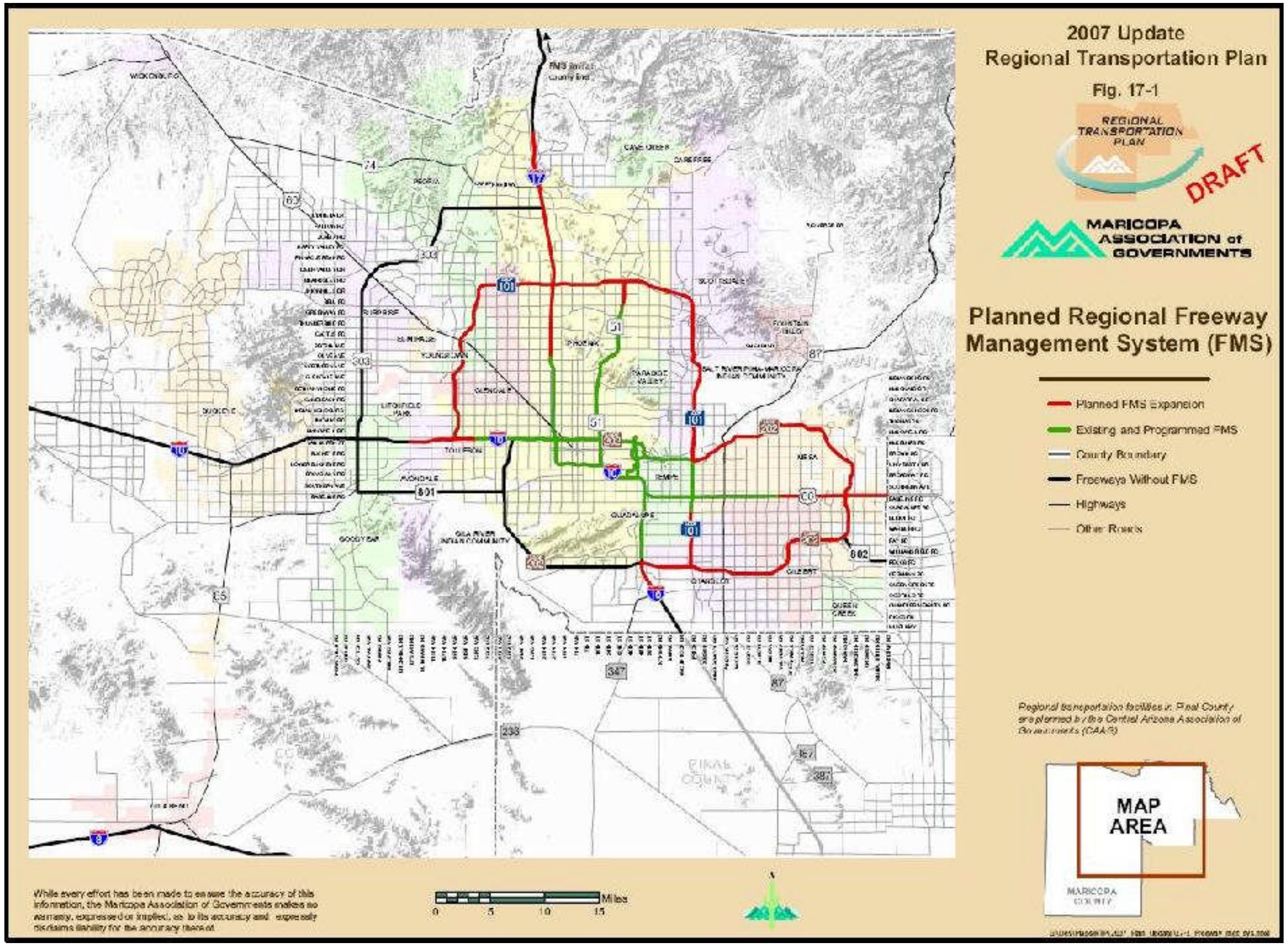


Figure 1.3-2: Jurisdictional Location and Areas
(Ref: MAG Regional Transportation Plan – 2007 Update; Extraction from Map)

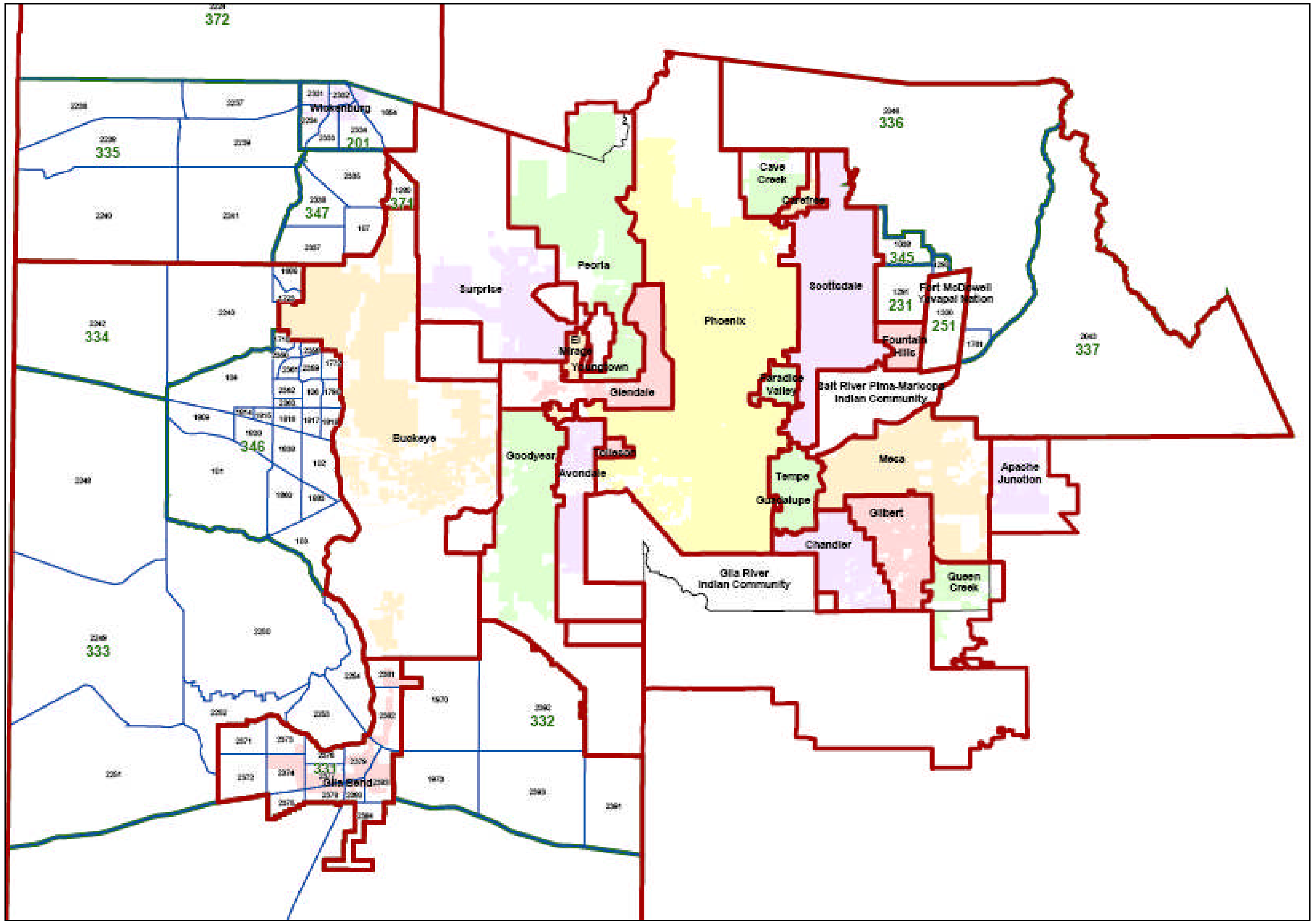


Table 1.3-1: Jurisdictions/Organizations with Common Interest Boundaries and Corridors (Color-coded by Population Projections for 2030)

North East	South East	North West	South West	Central Area
Carefree	Apache Junction	El Mirage	Avondale	ADOT FMC
Cave Creek	Chandler	Glendale	Buckeye	City of Phoenix TMC
Fountain Hills	Gila River	Peoria	Gila Bend	MCDOT TMC
Paradise Valley	Gilbert	Phoenix	Goodyear	MAG
Phoenix	Mesa	Surprise	Litchfield Park	County EOC
Salt River	Guadalupe	Wickenburg	Phoenix	State EOC
Scottsdale	Phoenix	Youngtown	Tolleson	Valley Metro Public Transit Mgt. Ctr.
	Queen Creek	Deer Valley Airport (Alt. to Sky Harbor)	Goodyear Airport (Alt. to Sky Harbor)	Sky Harbor International AP (Part of City of Phoenix ITS)
	Salt River			
	Tempe			
	ASEOC			

Notes: 2030 Population: XX < 20K; XX 20K to 50K; XX 50K to 100K; XX 100K to 250K; XX 250K to 500K; XX 500K to 1 Mil; XX > 1 Mil

There are number of different network topology solutions. **Figures 1.3-3, 1.3-4** and **1.3-5** present single, dual and triple ring topologies. **Figure 1.3-6** illustrates the architecture of a core Ethernet Ring and **figure 1.3-7** illustrates the core ring integrated with a subnet ring. **Figure 1.3-8** illustrates the use of an edge ring to interface jurisdictions that are remote from the backbone ring node. Edge rings would be deployed utilizing Gig-E and would preferably be interconnected to two nodes. Initially a folded edge ring could be utilized and the ring unfolded as perhaps more jurisdictional fiber is deployed. Whether an open or closed ring is deployed, edge network plans should included dual interconnections to the regional network hub(s) to increase reliability.

Jurisdictions that are candidates for edge networks include:

- El Mirage, Surprise, and Youngtown
- Carefree and Cave Creek
- Avondale, Buckeye, Goodyear and Tolleson (however Tolleson is close to a backbone node)

Apache Junction, Fountain Hills, Gila River, Gila Bend, and Wickenburg would be extended drops for a backbone node. Using an edge ring architecture, Gila Bend could be part of an edge ring extending from Buckeye and Wickenburg could be part of an edge ring standing from Surprise. Similarly, Litchfield Park could be part of an edge ring branching from Avondale.

Figure 1.3-3 Single Ring Network Topology

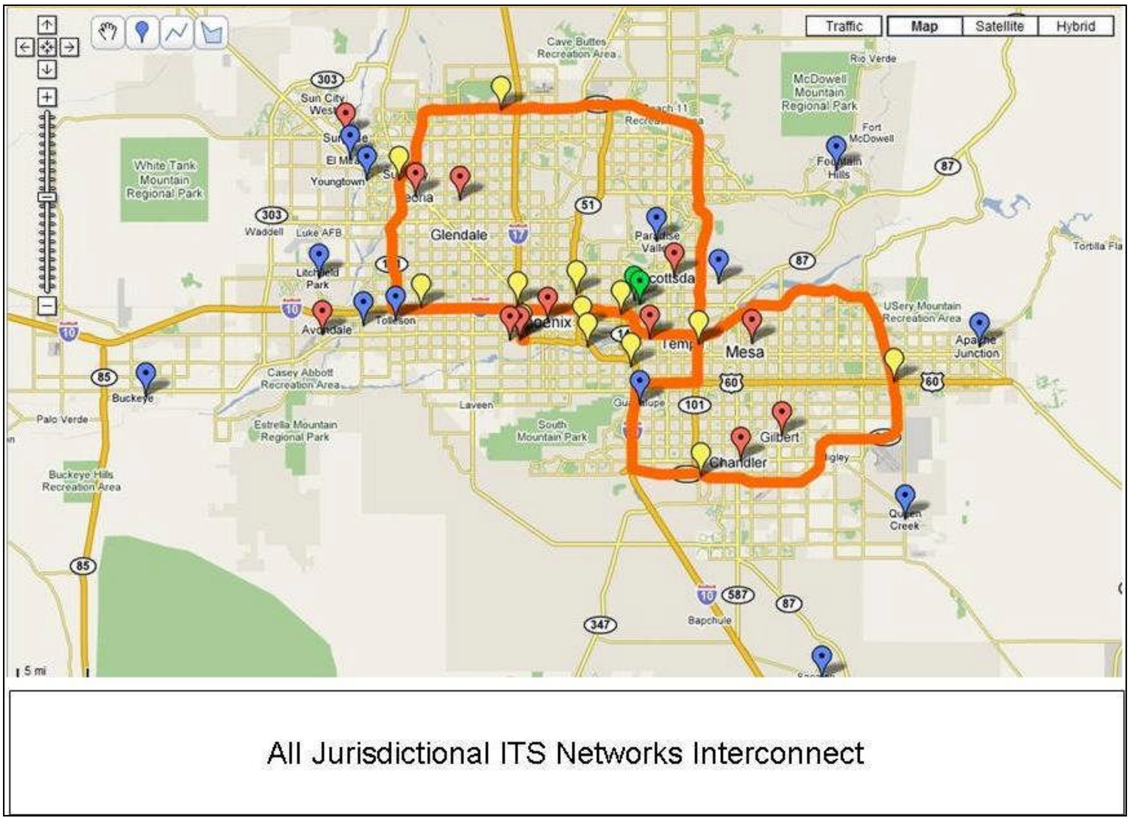


Figure 1.3-4 Two Ring Network Topology

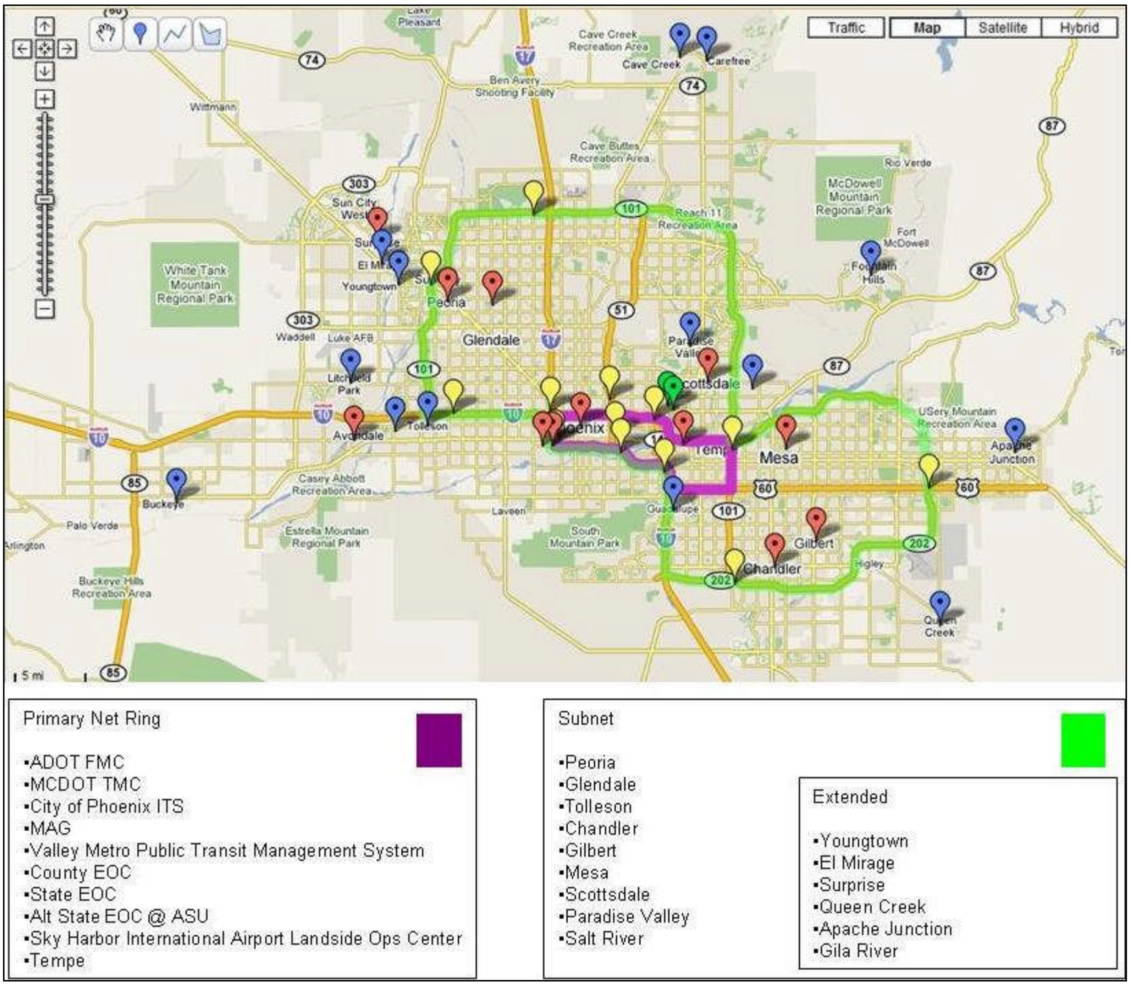


Figure 1.3-5 Three Ring Network Topology

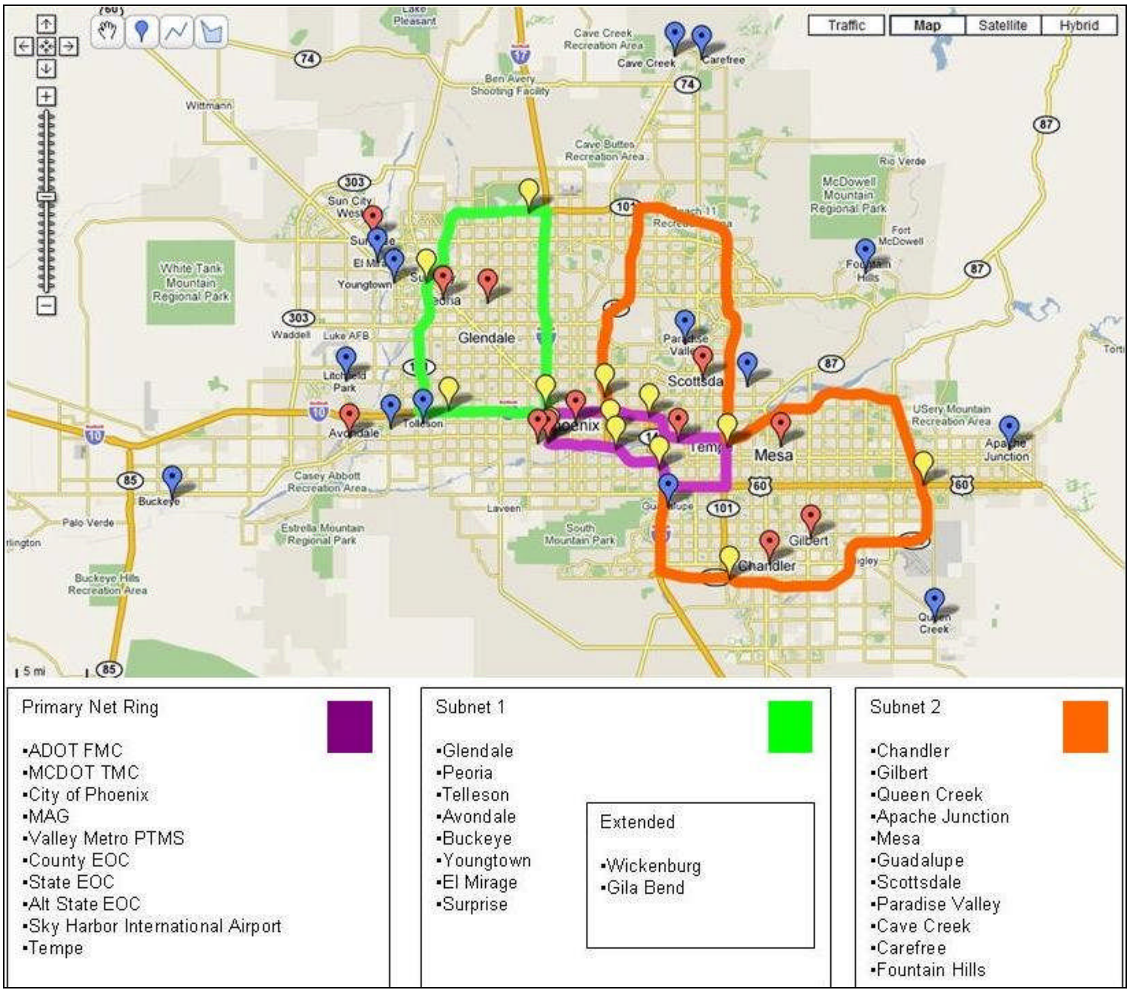


Figure 1.3-6: Core Ring Basic Architecture

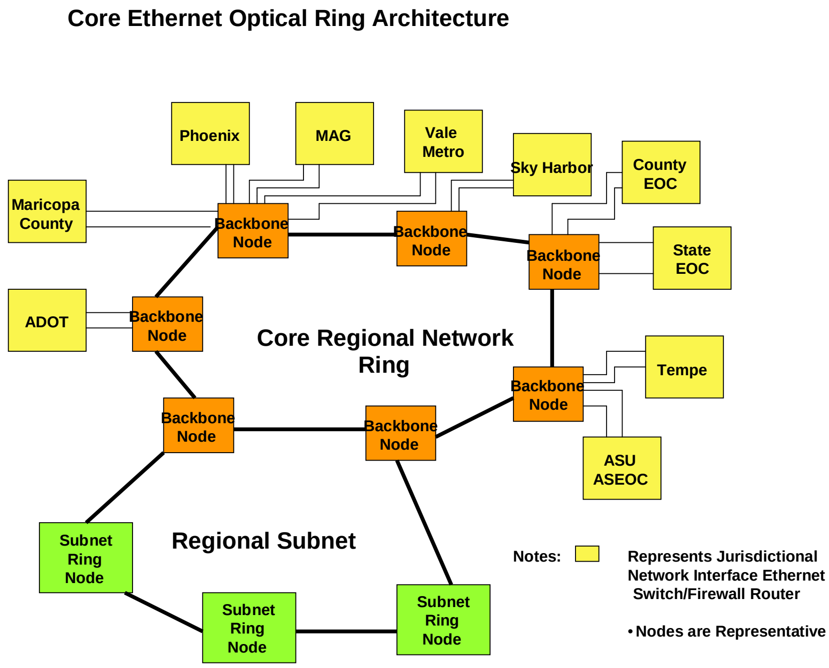


Figure 1.3-7: Dual Ring Network Architecture

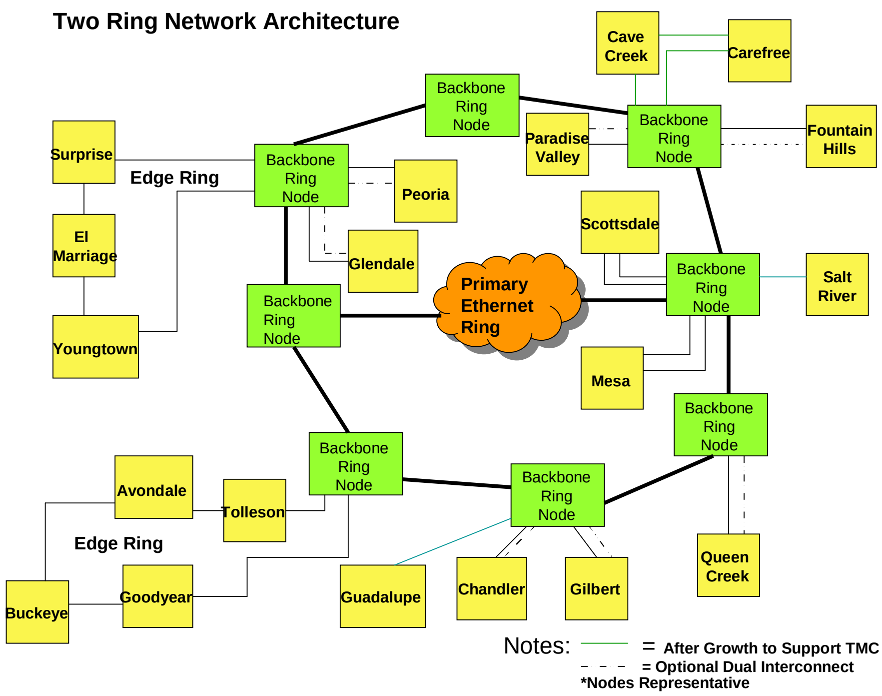
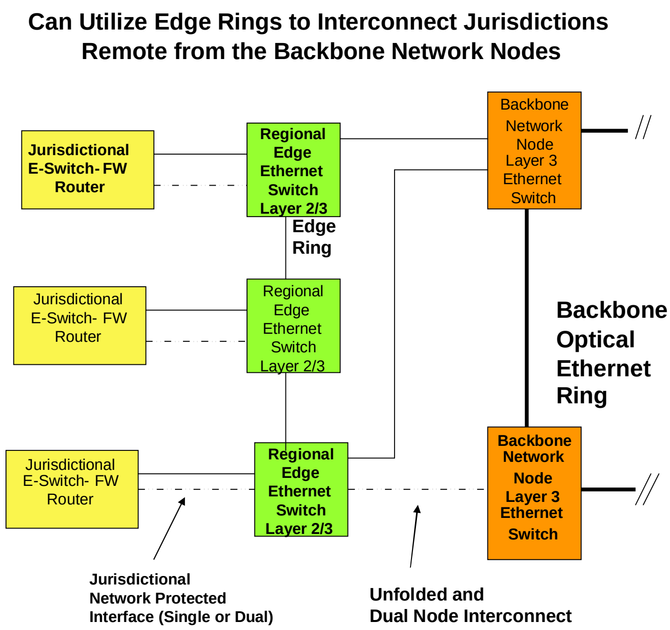


Figure 1.3-8: Example of Edge Ring to Interconnect Jurisdictions Remote from the Backbone Ring Node



Data loads on the ring configurations are presented in **table 1.3-2.** **Table 1.3-3** provides the pros and cons comparison of the three ring topologies.

Table 1.3-2: Data Rates per Ring
(Does Not Include Fault Rerouting)

Data Rate Per Ring (Gbps)

Ring Configurations	Core Ring 2020	Core Ring 2030	Subnet Ring 1 2020	Subnet Ring 1 2030	Subnet Ring 2 2030	Subnet Ring 2 2030
Single Ring	10.9	16.4	NA	NA	NA	NA
Dual Ring (Core and 1 Subnet)	6.3	9.0	4.6	7.4	NA	NA
Three Ring (Core Plus 2 Subnets)	6.3	9.0	1.8	3.4	2.8	4.0

Note: Does Not Consider Fault Recovery Load

Table 1.3-3: Comparison of ring topologies

Comparison of Topology Candidates

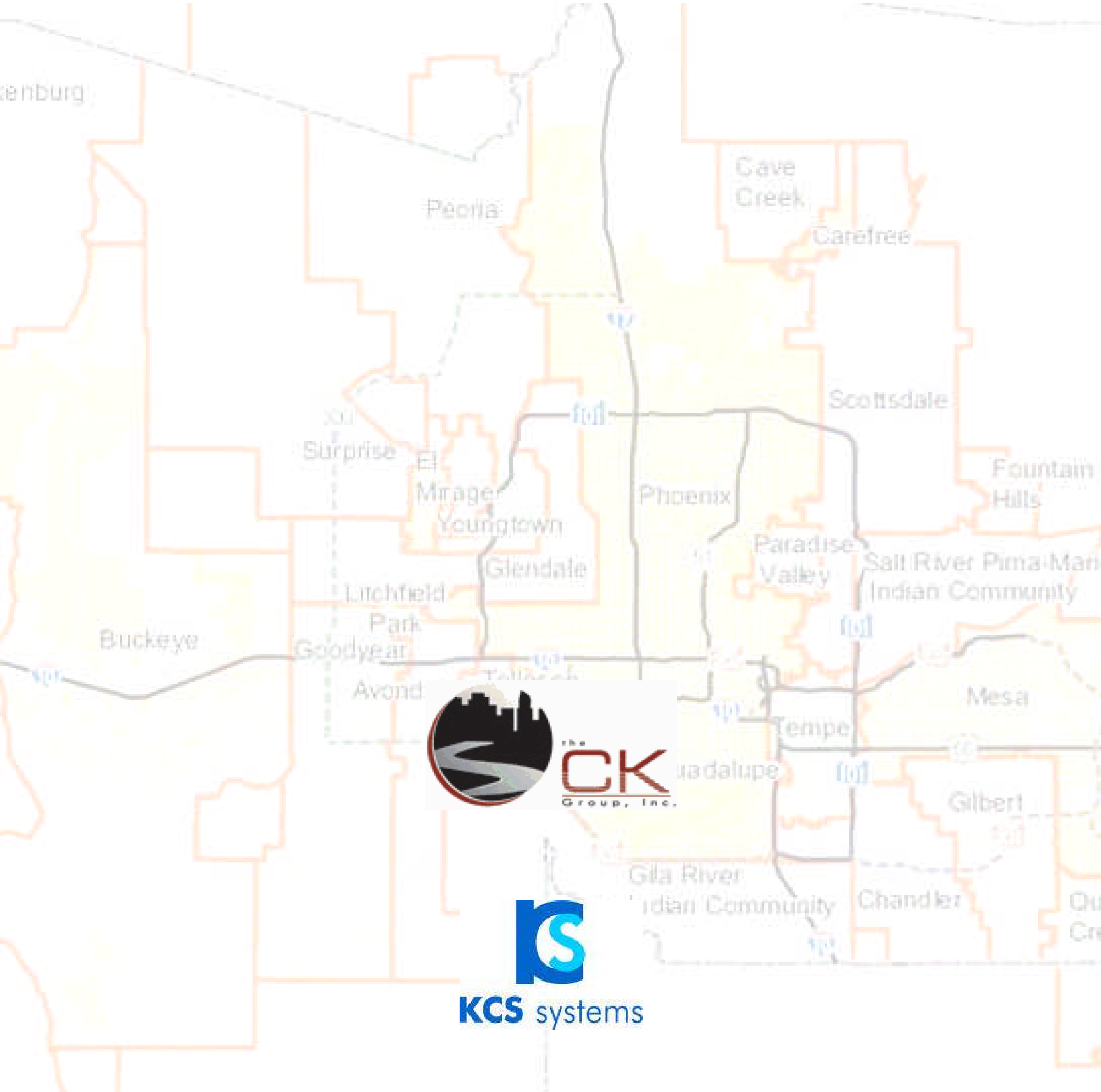
Backbone Ring Configuration	Pro	Con
Single Ring	• Simpler for Multicast PIM Recovery Upon Failure • Slightly Less Costly • Simpler to Manage/Maintain	• Susceptible to Segmentation with Multiple Fiber Breaks
Dual Ring	• Maintains Heavy Load on Central Ring • Less Susceptible to Ring Segmentation than Single Ring	• More Complex to Maintain than Single Ring • More Costly than Single Ring
Triple Ring	• Less Susceptible to Ring Segmentation than Dual Ring • Simpler to Build Out in Stages • Less Interruption During Expansion	• More Complex to Maintain than Single Ring • Multicast Recovery from Failure more Complex (Both for PIM Sparse and PIM Dense) • More Costly

For the following reasons, a three-ring topology is probably the best choice for the MAG regional communications network:

- Will most probably have to be built out in phases and the three-ring configuration best supports phased build-out.
- Improves load balancing on rings (however, with failure, rings must be designed to accommodate fault load)
- Provides improved protection against ring segmentation

1.4: Summary

In summary, optical Ethernet Technology is recommended, configured in a three-ring topology. Regional Ethernet Network nodes (backbone nodes) are independent of jurisdictional interconnect nodes. This maintains a protected interface to the jurisdictional networks that inter-work with the regional network. This enhances privacy of public information that may be on the jurisdictional network. The jurisdiction will be responsible for integration of jurisdictional ITS information supporting interoperability. Exceptions may be the County EOC and Sky Harbor International Airport Landside Operations Center. Analysis indicates that only the City of Phoenix, the City of Mesa and ADOT will require greater than 1 Gbps interface. Redundant interfaces are recommended, and where possible, interface to two backbone nodes.



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